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(54) **FLUID LEVEL MEASUREMENT SYSTEM AND METHOD**

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*G01F 23/296* (2006.01)

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CPC ..... *G01F 23/2962* (2013.01); *G01F 23/2968* (2013.01)

(58) **Field of Classification Search**  
USPC ..... 73/1.73, 290 V; 62/239  
See application file for complete search history.

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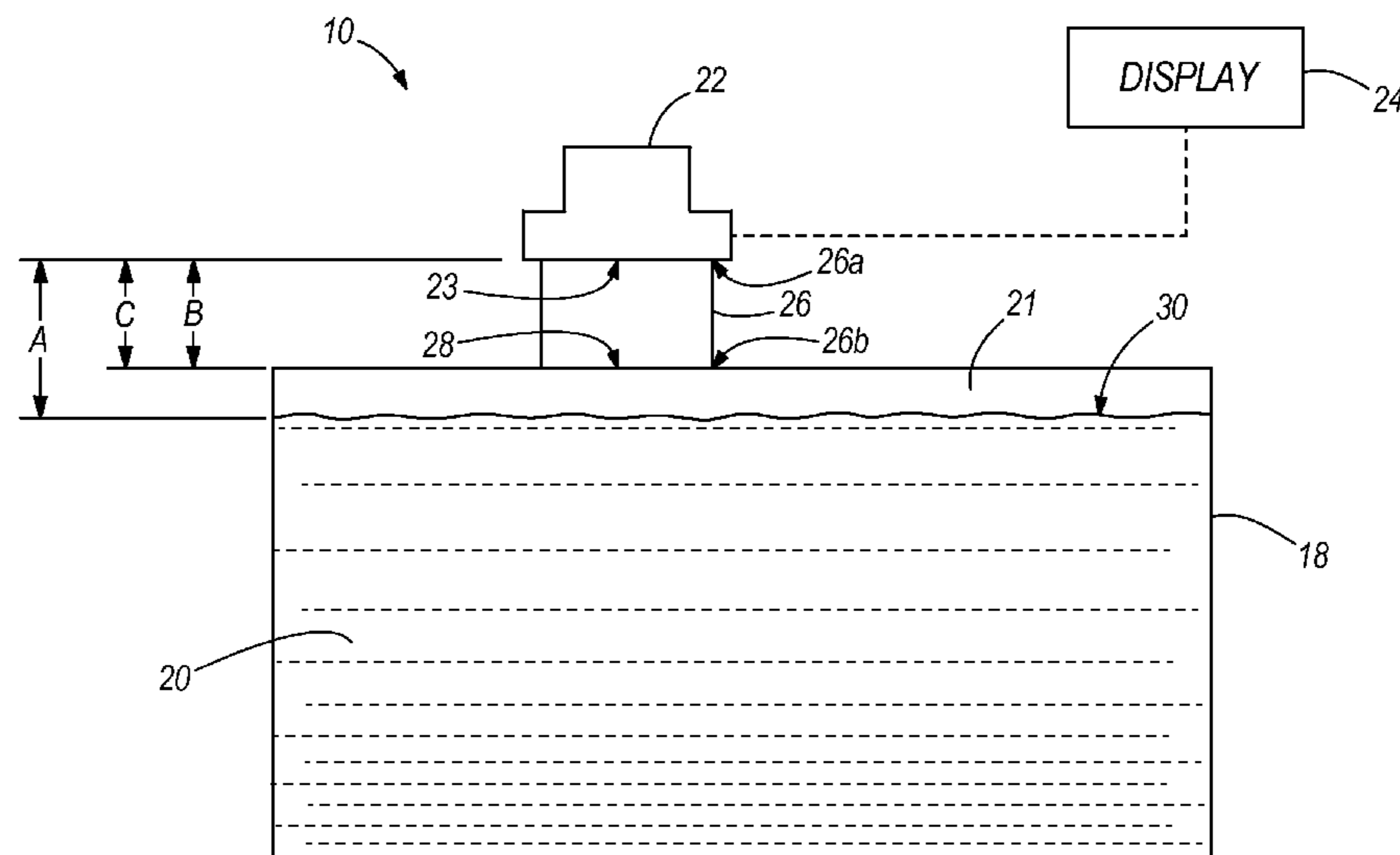
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(57) **ABSTRACT**

A method for measuring a fluid level in a tank containing a fluid for a transportable temperature controlled space. The method includes providing a temperature control system for the transportable temperature controlled space, providing a fluid level sensor for sensing a fluid level in the tank, generating fluid level signals with the fluid level sensor indicative of the fluid level in the tank, providing a fluid level algorithm for receiving the fluid level signals from the fluid level sensor and computing the fluid level in the tank, and inhibiting nondeterministic fluid level signals from being introduced to the fluid level algorithm.

**18 Claims, 6 Drawing Sheets**



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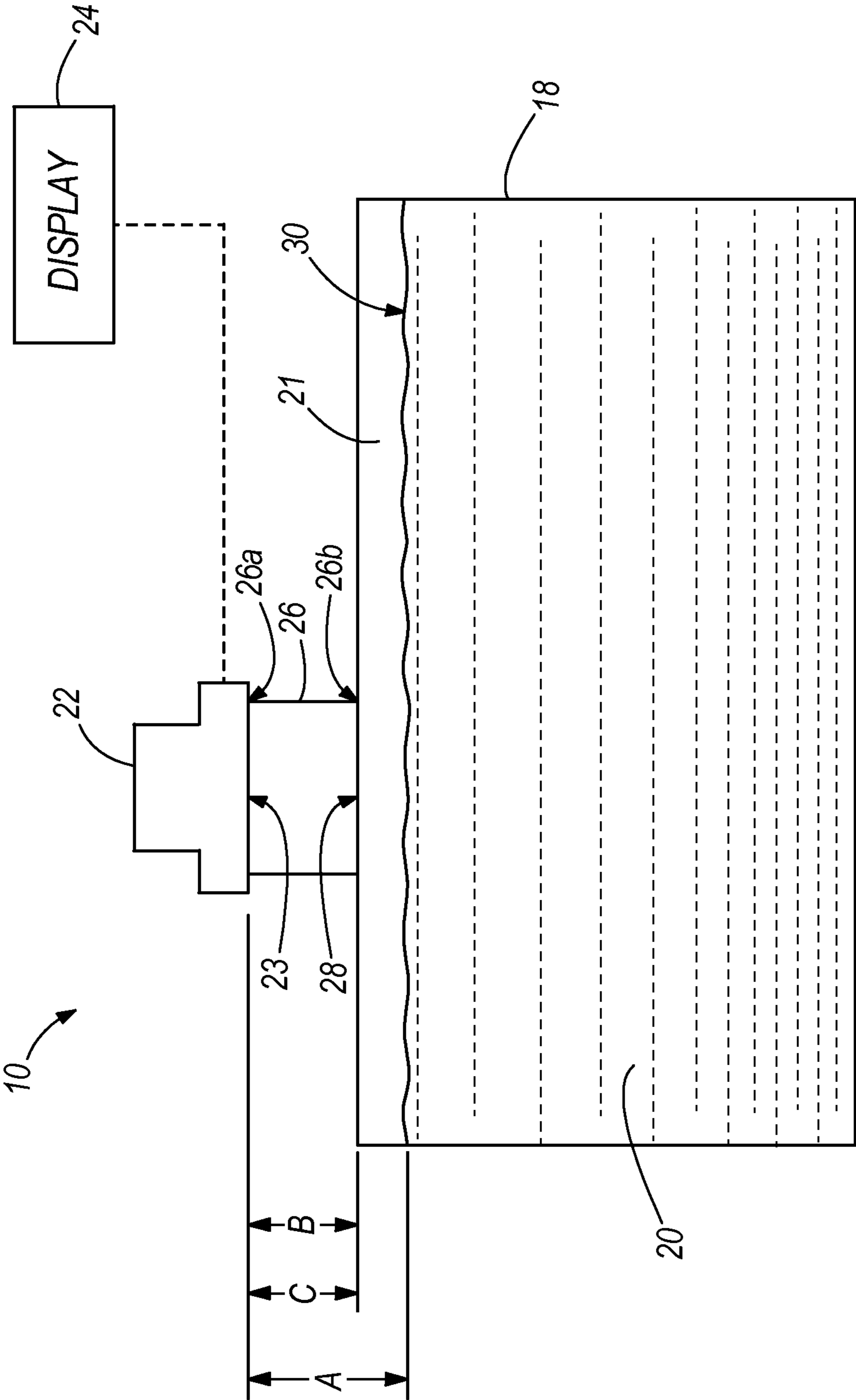


FIG. 1

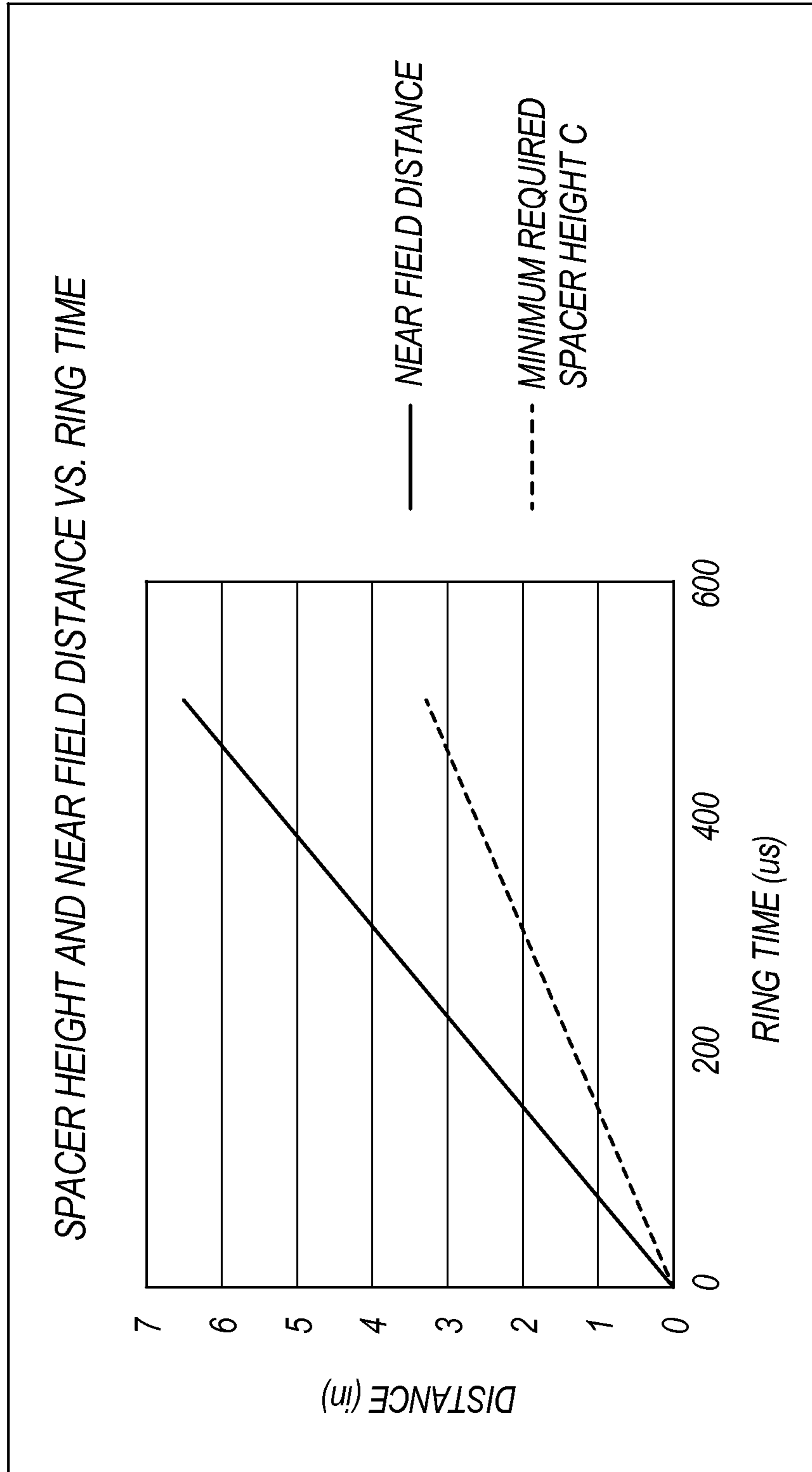


FIG. 2

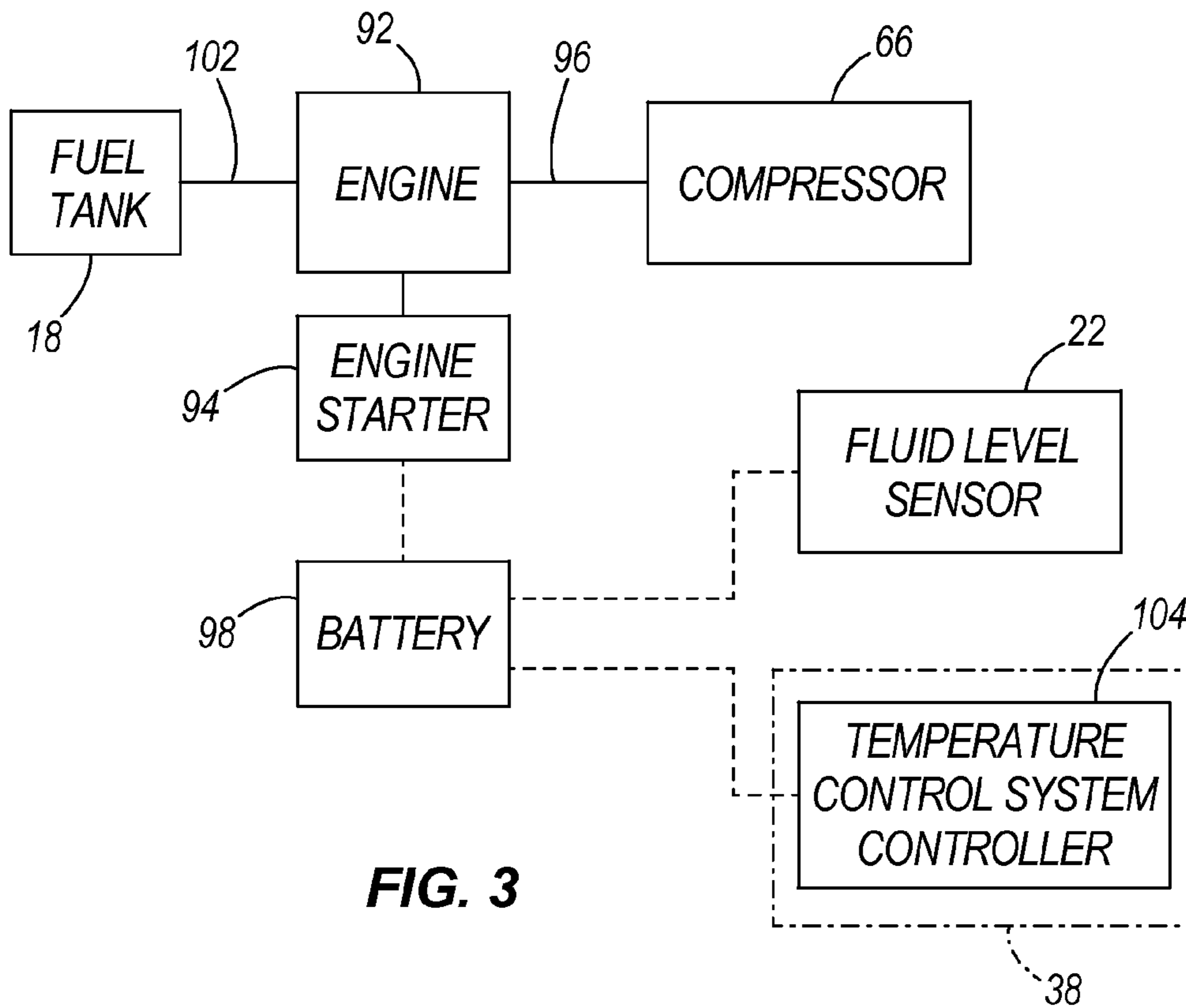


FIG. 3

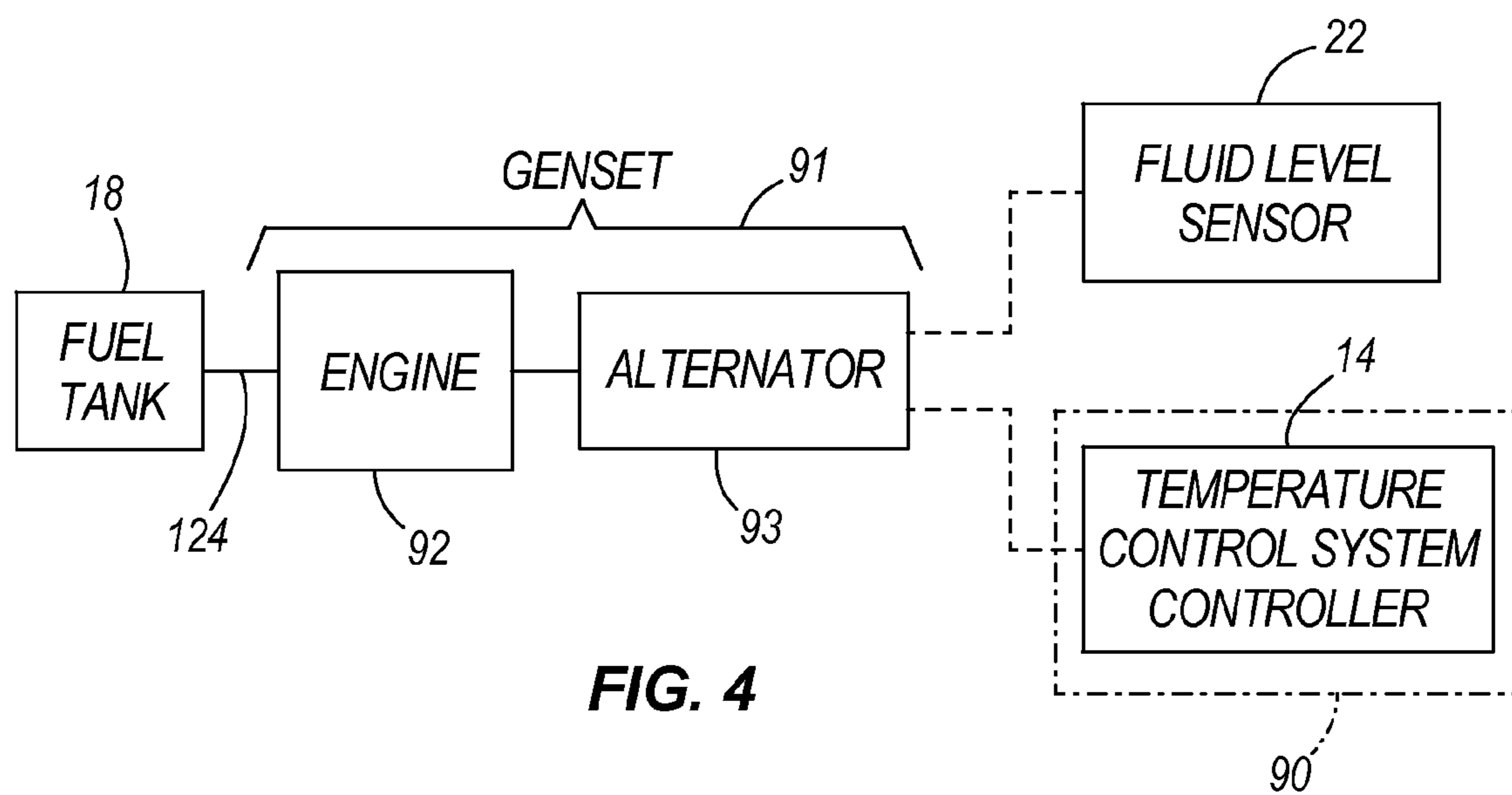


FIG. 4

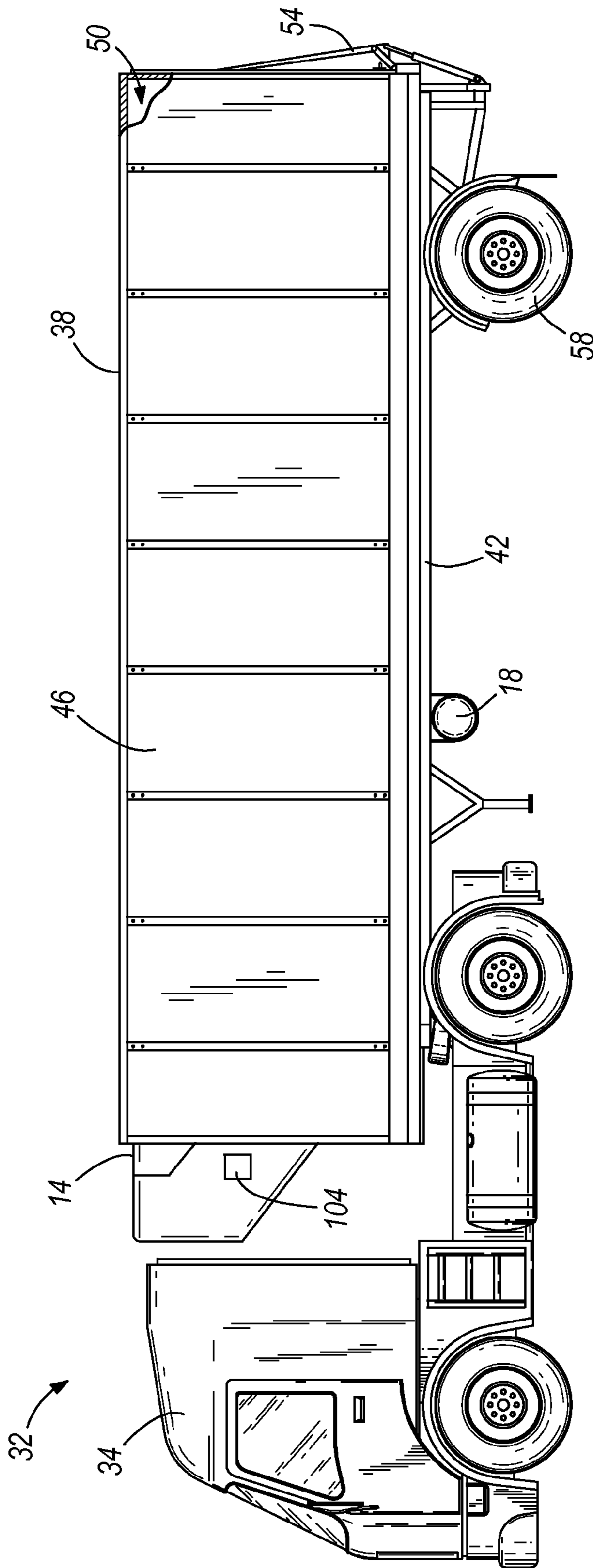


FIG. 5



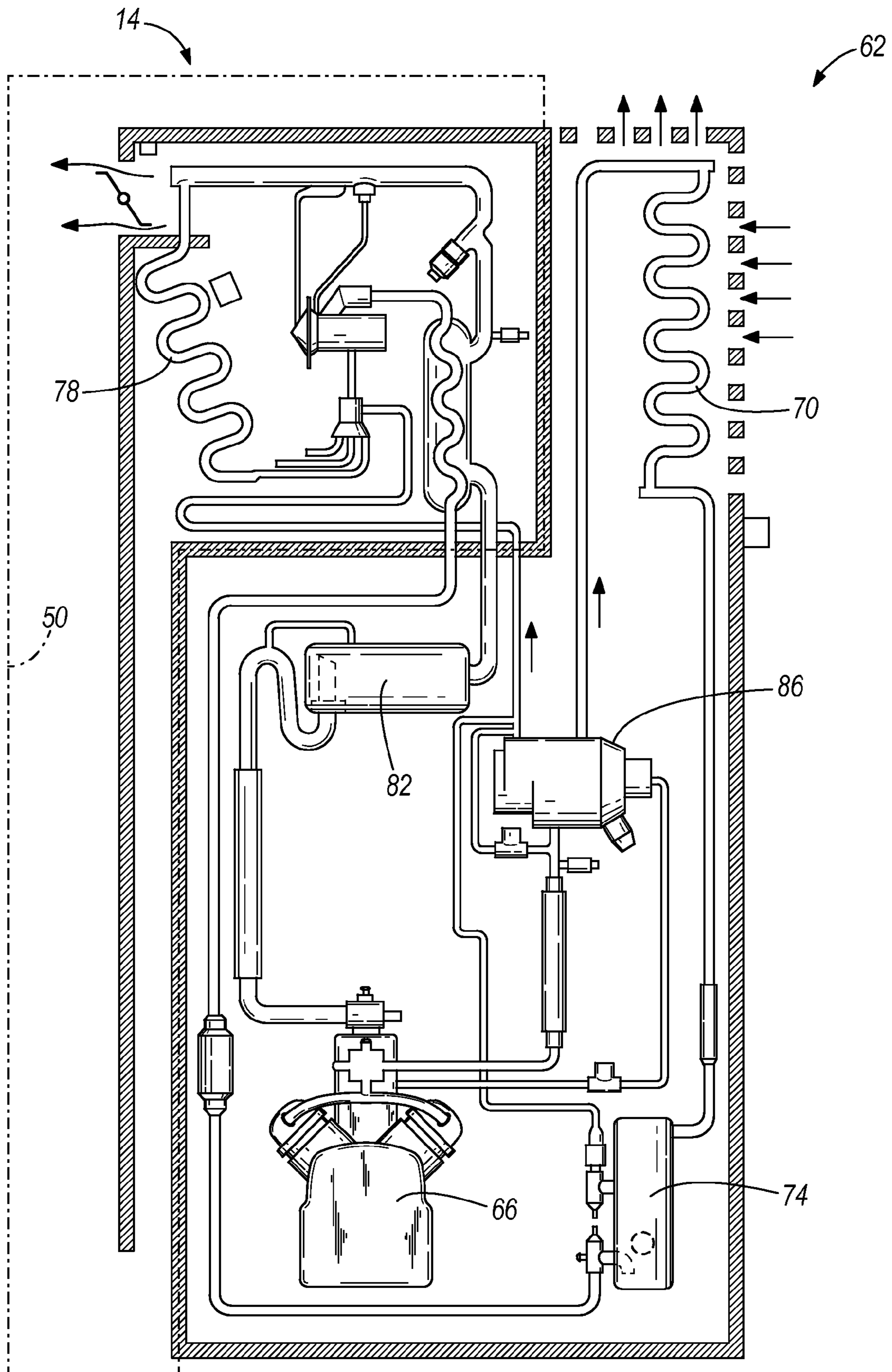


FIG. 6

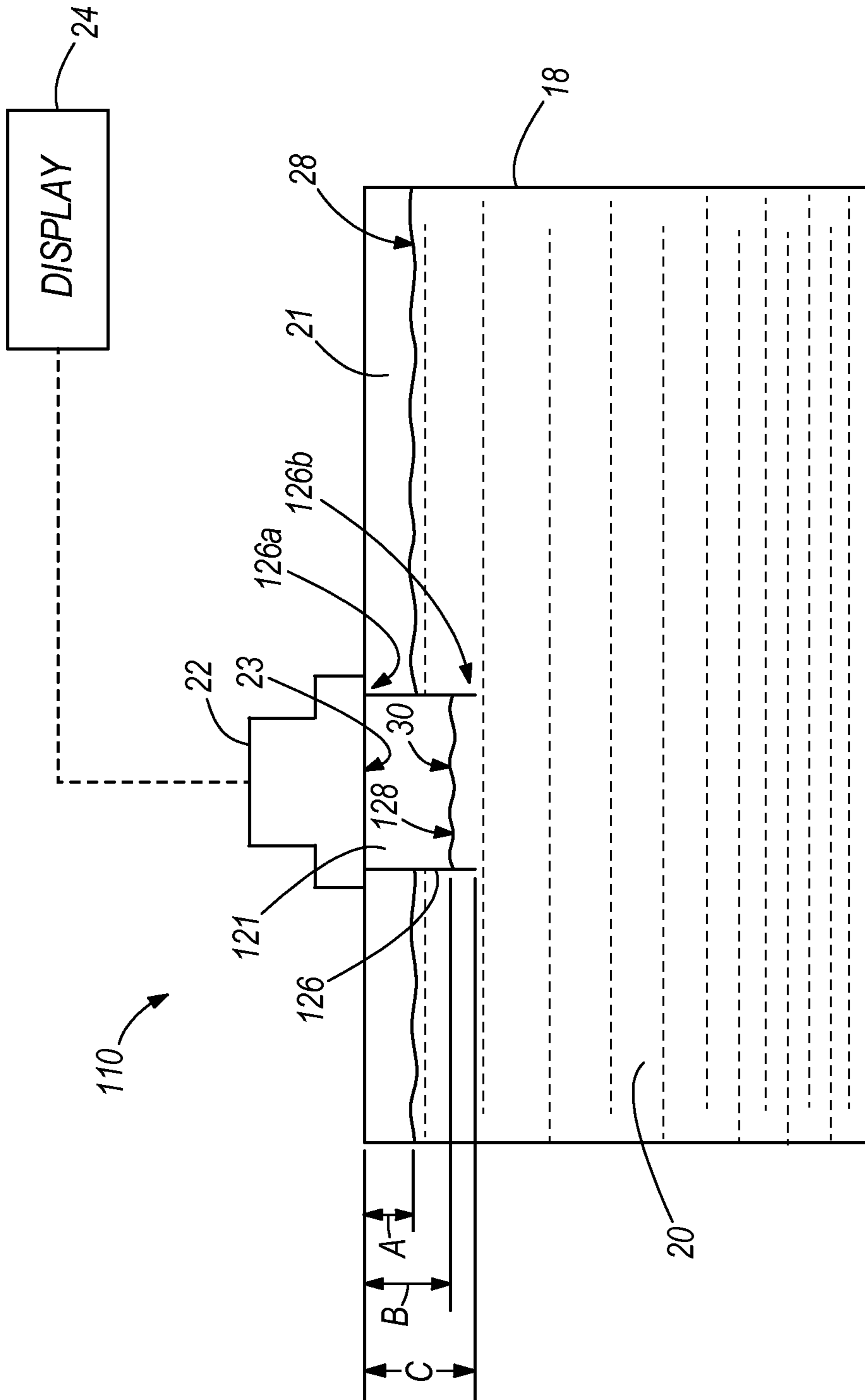


FIG. 7



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## FLUID LEVEL MEASUREMENT SYSTEM AND METHOD

### RELATED APPLICATIONS

This patent application is a continuation of U.S. patent application Ser. No. 13/078,620, filed Apr. 1, 2011, which claims priority to U.S. Provisional Patent Application No. 61/320,033 filed on Apr. 1, 2010, the entire contents of which are both incorporated herein by reference.

### BACKGROUND

The present invention relates to an apparatus and method for making ultrasonic fluid level measurements in a transport refrigeration application. Particularly, the invention relates to the position of a fluid level sensor for detecting a fuel level in a fuel tank associated with a transport temperature control system.

In a transport temperature control system application, a temperature controlled space is transported over a road, rail, sea, air or the like. As a result, fuel in a fuel tank for the temperature control system is subjected to vibrations from turbulence resulting from movement of the temperature controlled space. Furthermore, periodic stopping and starting of the temperature control system while the temperature controlled space is in transit causes periodic electrical noise associated with cranking of an engine that drives a compressor. Thus, the fluid level sensor is simultaneously subjected to vibration noise and electrical noise, which causes errors in the fluid level reading.

### SUMMARY

In one aspect, the invention provides a method for measuring a fluid level in a tank containing a fluid for a transportable temperature controlled space. The method includes providing a temperature control system for the transportable temperature controlled space, providing a fluid level sensor for sensing a fluid level in the tank, generating fluid level signals with the fluid level sensor indicative of the fluid level in the tank, providing a fluid level algorithm for receiving the fluid level signals from the fluid level sensor and computing the fluid level in the tank, and inhibiting nondeterministic fluid level signals from being introduced to the fluid level algorithm.

In another aspect, the invention provides a system for measuring a fluid level in a tank for a transportable temperature controlled space. The system includes a transport temperature control system for conditioning a load space of the transportable temperature controlled space, and a fluid level measurement system for measuring the fluid level. The fluid level measurement system includes a tank containing a fluid, a fluid level sensor for generating fluid level signals indicative of the fluid level in the tank, and a fluid level algorithm for receiving the fluid level signals from the fluid level sensor and computing the fluid level in the tank. The fluid level measurement system is configured to inhibit nondeterministic fluid level signals from being introduced to the fluid level algorithm.

In yet another aspect, the invention provides a method for measuring a fluid level in a tank containing a fluid. The method includes providing a fluid level sensor for measuring a fluid level in the tank, providing a temperature control system for a transportable temperature controlled space, providing a power source, powering the fluid level sensor and the temperature control system with the same power source, gen-

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erating fluid level signals with the fluid level sensor indicative of the fluid level in the tank, and inhibiting nondeterministic fluid level signals.

Other aspects of the invention will become apparent by consideration of the detailed description and accompanying drawings.

### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic illustration of a fluid level measurement system for a tank in accordance with the present invention.

FIG. 2 is a plot of spacer height and near field distance vs. ring time for the fluid level measurement system of FIG. 1.

FIG. 3 is a schematic diagram of a container power system for powering the fluid level measurement system.

FIG. 4 is a schematic diagram of a trailer power system for powering the fluid level measurement system.

FIG. 5 is an image of a tractor and trailer having the tank of FIG. 1.

FIG. 6 is a schematic diagram of a temperature control system for the trailer of FIG. 5.

FIG. 7 is a schematic illustration of another construction of a fluid level measurement system for a tank in accordance with the present invention.

### DETAILED DESCRIPTION

Before any constructions of the invention are explained in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the following drawings. The invention is capable of other constructions and of being practiced or of being carried out in various ways.

FIG. 1 illustrates a fluid level measurement system 10 for use with a transport temperature control system 14 (FIGS. 3-6). The fluid level measurement system 10 includes a fluid tank 18 for containing a fluid 20 and a fluid vapor 21, such as a fuel tank containing a fuel and fuel vapor, and a fluid level sensor 22 having a face 23. In the illustrated construction, the tank 18 is a cylindrical diesel fuel tank coupled horizontally to a vehicle (FIG. 5) such that a longitudinal axis thereof lies substantially parallel to the ground. A spacer 26 is coupled with the tank 18 adjacent an opening in the tank 18 and extends from the top of the tank 18. The spacer 26 is a tubular structure having a wall extending axially from an outer surface of the tank 18 and having first and second open free ends 26a, 26b, respectively. The sensor 22 is coupled with the spacer 26 and positioned coaxially with respect to the spacer 26. The face 23 of the sensor 22 is positioned adjacent the first free end 26a and the second free end 26b abuts the tank 18 and is in communication with an interior of the tank 18.

In the illustrated construction, the fluid level sensor 22 is an ultrasonic fluid level sensor including a transducer that emits a sound, by way of an initial vibration, in the direction of a surface 30 of the fluid 20, preferably in a direction perpendicular to the surface 30 of the fluid 20. The sound is emitted from the sensor 22 at the face 23 of the sensor 22. The sensor 22 includes a receiver that senses an echo of the initial sound reflected off the surface 30 and records a time between emitting the sound and receiving the echo. Based on the speed of sound through the medium through which the sound travels, e.g., air and fuel vapor 21, and the recorded time, a separation distance A between the sensor 22 and the surface 30 of the fluid 20 is calculated. The system 10 includes a fluid level



algorithm that is calibrated such that the distance A is associated with a fluid level of the tank. The fluid level is displayed on a display 24.

The spacer 26 is sandwiched between the tank 18 and the sensor 22 to provide a minimum separation distance B between the sensor 22 and the surface 30 of the fluid 20 at a maximum fluid level 28. The maximum fluid level 28 is a predetermined level that the tank 18 is designed to hold and need not be the absolute physical maximum of the tank 18. For example, a fuel-dispensing nozzle typically shuts off automatically when the fuel reaches a fluid level that is less than the physical maximum of the tank 18. In this case, the maximum fluid level 28 is the level at which the fuel-dispensing nozzle shuts off, and the fluid level algorithm is calibrated to associate a reading of "FULL" with the maximum fluid level 28. The tank 18 includes a fill neck (not shown) for receiving the fuel-dispensing nozzle. The position of the fill neck (e.g., height) on the cylindrical tank 18 can also define the maximum fluid level 28. The minimum separation distance B occurs when the fuel tank 18 is full and is the minimum distance necessary to inhibit nondeterministic signals, which lead to erroneous fluid level readings by the sensor 22, as will be described in greater detail below. While the minimum separation distance B is constant and unique to a particular configuration of the fluid level measurement system 10, the separation distance A is variable depending upon the level of the fluid 20.

The minimum separation distance B is equal to, or in some constructions may be greater than, half the near field distance. The near field distance is calculated using the equation  $D_{nf} = V_{sd} * T_r$ , where  $D_{nf}$  is the near field distance,  $V_{sd}$  is the speed of sound through the medium through which the sound travels, e.g., the fluid vapor 21 and air, and  $T_r$  is the ring period of the transducer. As described above, the transducer emits the sound by way of an initial vibration; however, the transducer continues to vibrate at a decreasing magnitude after the initial vibration. The ring period is the time for the vibrations of the transducer to settle, or decrease, below a threshold of the sensor's receiver, i.e., to reach a magnitude of vibration that the receiver of the sensor 22 can no longer detect. In other words, the near field distance is equal to the distance that the sound travels through the medium during the ring period.

The fluid level measurement system 10 is configured based on the near field distance such that the sensor 22 is positioned at a distance from the surface 30 of the fluid 20 that is equal to or greater than half the near field distance when the tank is full 22, as indicated by the following equation:

$$B \geq \frac{V_{sd} * T_r}{2}$$

That is, the minimum separation distance B is equal to or greater than half the near field distance.

The spacer 26 is positioned vertically with respect to gravity and is sized to provide a spacer height C such that the sensor 22 and the surface 30 of the fluid 20 are separated by at least half the near field distance when the tank 18 is full. FIG. 2 is a plot of the minimum required spacer height C and near field distance vs. ring time, or ring period. In the illustrated construction, the spacer height C is approximately equal to the minimum separation distance B. The spacer height C depends on the construction of the tank 18. In the illustrated construction, the sensor 22 is employed with a diesel fuel tank 18 in which the spacer 26 extends between the maximum fluid level 28 and the face of the sensor 22, as can be seen in FIG.

1. In other constructions, the sensor 22 may be employed with other types of tanks suited for holding fluid in mobile applications. In some constructions, other relationships between spacer height C and minimum separation distance B are possible depending on the geometry of the tank 18. In other constructions, a spacer is not necessary to provide a sufficient minimum separation distance B between the sensor 22 and the maximum fluid level 28.

In the illustrated construction of FIG. 1, the sensor 22 has a ring period of 500 microseconds which corresponds to a near field distance of approximately 6.5 inches. Therefore, the minimum separation distance B is approximately 3.25 inches. Inherently, the separation distance A is greater than half the near field distance when the tank 18 is not full.

The fluid level measurement system 10 is preferably employed with a transport temperature control system fuel tank 18, such as for a truck, a trailer, a shipping container, a rail container, a van or another transport vehicle that stores and/or carries goods that must be maintained in a temperature controlled environment. However, in other constructions, other types of tanks for other applications may be used.

In one construction, illustrated in FIGS. 3 and 5, the fuel tank 18 and fluid level measurement system 10 are coupled to a transport vehicle 32 including a tractor 34 and trailer 38. As shown in FIG. 5, the trailer 38 includes a frame 42 and an outer wall 46 supported on the frame 42 for substantially enclosing a temperature controlled load space 50. Doors 54 are supported on the frame 42 for providing access to the load space 50. In some constructions, the load space 50 can include a partition or an internal wall for at least partially dividing the load space 50 into sub-compartments, including two or more load space zones, each of which can be maintained at a different temperature or a different humidity. A plurality of wheels 58 are provided on the frame 42 to permit movement of the vehicle 32 across the ground. In some constructions, wheels and/or rails for a railroad or a boat vessel can be used for transporting temperature controlled containers.

FIG. 6 illustrates one construction of a temperature control system 14 that conditions the load space 50 of the trailer 38. The temperature control system 14 includes a refrigeration circuit 62 having a compressor 66, a condenser 70, a receiver 74, an evaporator 78 and an accumulator 82 connected in series, as is well understood in the art. The refrigeration circuit 62 may also include other components well known in the art, such as a three-way switching valve 86 for switching between a heating mode and a cooling mode. The temperature control system is fully described in U.S. Pat. No. 6,367,269 titled "ELECTRONIC THROTTLING VALVE DIAGNOSIS AND PREVENTATIVE SHUTDOWN CONTROL," assigned to the same assignee as the present invention, the content of which is hereby fully incorporated herein by reference.

The compressor 66 is operatively coupled to an engine 92. As shown schematically in the construction of FIG. 3, the engine 92, such as a diesel engine, is coupled to the compressor 66 by a transmission 96 for driving the compressor 66. The fuel tank 18 supplies fuel to the engine 92 by way of a fuel line 102. FIG. 3 further illustrates a power source, such as a battery 98, for powering the fluid level sensor 22, for powering a controller 104 for the temperature control system, and for powering an engine starter 94 for starting the engine 92 when cooling or heating is needed. Other components of the temperature control system 14 may also be powered by the battery 98.

In other constructions, the engine 92 may include the vehicle engine or a gasoline engine. Other arrangements are



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possible and may be implemented, as desired. The fuel tank 18 may supply fuel to one or more of the engines employed.

FIG. 4 illustrates another construction in which the fluid level sensor 22 is employed with a temperature controlled transport container 90. For shipments of perishable goods, the temperature control system 14 may be employed to heat and/or cool the container 90. The transport container 90 may be transported by a variety of modes, such as by railcar, barge and truck. While the transport container 90 is stationary, such as while stored in a warehouse, on a dock, or near an airport, an external source of power such as utility electricity may be connected for powering the temperature control system 14. If the container 90 is not provided with an external power source, a generator set 91 may be provided to power the temperature control unit 14. For example, when the container is in transit by railcar, barge, or truck, the generator set 91 may be necessary. The generator set 91 includes the engine 92 to drive an alternator 93 which in turn provides electric power to the temperature control system 14, specifically the compressor 66. Thus, the engine 92 is operatively connected to the compressor 66. The alternator 93 also provides electric power to the fluid level sensor 22.

FIG. 7 illustrates another construction of a fluid level measurement system 110 having an internal spacer 126. Elements of this construction that are similar to the construction of FIG. 1 are given similar reference numerals. The internal spacer 126 is positioned vertically with respect to gravity. The internal spacer 126 provides the minimum separation distance B between the face 23 of the sensor 22 and a maximum fluid level 128 of the fluid within the internal spacer 126, which is lower than the maximum fluid level 28 of the tank 16, by trapping an air/vapor bubble 121 inside the spacer 126 to push the maximum fluid level 128 inside the spacer 126 away from the face of the sensor 23, much like submerging a cup upside down in water. The internal spacer 126 is a tubular structure having a wall extending axially and having first and second open free ends 126a, 126b, respectively. The face 23 of the sensor 22 is positioned adjacent the first free end 126a and the second free end 126b is in communication with the interior of the tank 18.

The height C of the internal spacer 126 is at least equal to the minimum required spacer height shown in FIG. 2, as discussed above, and is preferably greater than the minimum required spacer height to account for possible tilting of the tank 18 or sloshing of the fluid within the internal spacer 126. If the tank 18 and internal spacer 126 are tilted or if sloshing occurs, the air/vapor bubble 121 may escape from the internal spacer 126, raising the level 128 closer to the level 28. Therefore, the actual height C of the internal spacer 126 is preferably greater than the minimum required spacer height C. For example, if the ring time of the transducer is 350 microseconds, the minimum spacer height C is approximately 2.4 inches, as plotted in FIG. 2. The actual height of the internal spacer may be chosen to be 3.5 or 4 inches to reduce the chance of air/vapor escaping. Thus, similar to the construction described in FIG. 1, the minimum separation distance B is equal to or greater than half the near field distance. In some constructions, the internal spacer 126 may include a flange for inhibiting the air/vapor bubble 121 from escaping.

In operation, the fluid level sensor 22 is powered by the same power source that provides power to the temperature control system 14. In the construction of FIG. 4, a generator set 91 provides power to the fluid level sensor 22 and the temperature control system 14. In the construction of FIG. 3, a battery provides power to the fluid level sensor 22 and the engine starter 94, which starts the engine 92 to drive the

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compressor 66 of the temperature control system 14. In other constructions, other types of suitable power sources may be employed.

The output power, oscillator frequency, and analog circuitry of the fluid level sensor 22 depend on a constant input voltage. During startup of the compressor 66 of the temperature control system 14, which occurs as needed while the trailer 38 or container 90 is in transit, the power source 98, 91 is subjected to a heavy load, e.g., cranking, causing the voltage supply to the fluid level sensor 22 to droop and be unstable (e.g., power supply noise).

While the trailer 28 or container 90 is in transit, vibrations from movement over the road or rail, or other turbulence, causes vibrations in the surface 30 of the fluid 20. The combination of power supply noise and vibration noise in the fluid surface 30, simultaneously, may result in a nondeterministic signal. A nondeterministic signal introduced to the fluid level algorithm results in multiple possible fluid levels being computed, causing glitches in the fluid level measurement, such as rapid changes in the fluid level reading in a short period of time, e.g., more than 4% in less than 10 seconds, when the algorithm selects the wrong fluid level out of the possible fluid levels.

When the sensor 22 is spaced from the surface 30 of the fluid 20 by at least half the near field distance, the nondeterministic signal is inhibited and glitches are avoided. Thus, the fluid level measurement system 10, 110 is configured such that the sensor 22 is spaced from the maximum fluid level 28, 128 of the tank 18 by at least half the near field distance such that the sensor 22 is spaced from the fluid surface 30 by a distance greater than half the near field distance when the tank 18 is not full. The spacer 26, 126 is sized accordingly to provide the necessary minimum separation distance B.

Thus, the invention provides, among other things, a fluid level sensor spaced from a maximum fluid level of the tank by a distance greater than or equal to half the near field distance of the sensor.

What is claimed is:

1. A method for measuring a fluid level in a tank containing a fluid, the tank being included in a temperature control system for a transportable temperature controlled space, the method comprising:

sensing a fluid level in a tank using a fluid level sensor, the sensing including:

directing a fluid level signal toward a surface of the fluid such that a fluid level signal travels through a fluid vapor and air and is reflected from the surface of the fluid back toward the fluid level sensor; and

receiving the fluid level signal through the fluid vapor and air after it is reflected from the surface of the fluid;

generating fluid level signals with the fluid level sensor indicative of the fluid level in the tank;

receiving the fluid level signals from the fluid level sensor; computing the fluid level in the tank, using a controller for the temperature control system, based on the fluid level signals received from the fluid level sensor; and

inhibiting nondeterministic fluid level signals from being introduced by positioning the fluid level sensor a distance from a maximum fluid level, the distance being half the distance that sound travels through the fluid vapor and air toward the surface of the fluid during a ring period of the fluid level sensor.

2. The method of claim 1, further comprising: powering both the fluid level sensor and the temperature control system with a power source.



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3. The method of claim 2, further comprising:  
subjecting the fluid level sensor to power supply noise.
4. The method of claim 3, further comprising:  
inhibiting nondeterministic fluid level signals from being  
introduced while subjecting the fluid level sensor to  
power supply noise.
5. The method of claim 4, further comprising:  
receiving a fuel for the temperature control system in the  
tank.
6. The method of claim 4, wherein the powering the tem-  
perature control system includes powering an engine starter  
for an engine.
7. The method of claim 4, wherein the powering the fluid  
level sensor and the temperature control system with the same  
power source includes powering the fluid level sensor and the  
temperature control system with at least one of a battery and  
an alternator.
8. The method of claim 2, further comprising:  
receiving a fuel for the temperature control system in the  
tank.
9. The method of claim 8, wherein the powering the tem-  
perature control system includes powering an engine starter  
for an engine configured to receive the fuel from the tank.
10. The method of claim 2, wherein the powering the fluid  
level sensor and the temperature control system with the same  
power source includes powering the fluid level sensor and the  
temperature control system with at least one of a battery and  
an alternator.
11. A system for measuring a fluid level in a tank for a  
transportable temperature controlled space, the system com-  
prising:  
a transport temperature control system for conditioning a  
load space of the transportable temperature controlled  
space; and  
a fluid level measurement system for measuring the fluid  
level comprising:  
a tank containing a fluid;  
a fluid level sensor configured to be directed toward a  
surface of the fluid configured to generate fluid level  
signals indicative of the fluid level in the tank, wherein  
the fluid level signals from the fluid level sensor are  
reflected from the surface of the fluid;  
the fluid level sensor positioned a distance from the maxi-  
mum fluid level, the distance being about half the dis-  
tance that sounds travels through the fluid vapor and air  
toward the surface of the fluid during a ring period of the  
fluid level sensor; and  
a controller configured to receive the fluid level signals  
from the fluid level sensor and compute the fluid level in  
the tank, wherein the fluid level measurement system is  
configured to inhibit nondeterministic fluid level signals  
from being introduced.

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12. The system of claim 11, further comprising:  
a power source coupled to both the fluid level sensor and  
the temperature control system, the power source con-  
figured to power the fluid level sensor and the tempera-  
ture control system.
13. The system of claim 12, wherein the temperature con-  
trol system further comprises:  
a compressor for compressing a refrigerant, and  
wherein the tank is a fuel tank configured to provide a fuel  
to the compressor.
14. The system of claim 13, wherein the temperature con-  
trol system further comprises:  
an engine configured to drive the compressor; and  
an engine starter configured to start the engine,  
wherein the power source is configured to power the engine  
starter.
15. The system of claim 14, wherein the power source  
includes at least one of a battery and an alternator.
16. A method for measuring a fluid level in a tank contain-  
ing a fluid, the tank being included in a temperature control  
system for a transportable temperature controlled space, the  
method comprising:  
Measuring a fluid level in the tank using a fluid level sensor,  
the measuring including:  
directing a fluid level signal toward a surface of the fluid  
such that a fluid level signal travels through a fluid vapor  
and air and is reflected from the surface of the fluid back  
toward the fluid level sensor; and  
receiving the fluid level signal through the fluid vapor and  
air after it is reflected from the surface of the fluid;  
powering the fluid level sensor and the temperature control  
system with the same power source;  
generating fluid level signals with the fluid level sensor  
indicative of the fluid level in the tank; and  
inhibiting nondeterministic fluid level signals by position-  
ing the fluid level sensor a distance from the maximum  
fluid level, the distance being about half the distance that  
sound travels through the fluid vapor and air toward the  
surface of the fluid during a ring period of the fluid level  
sensor.
17. The method of claim 16, further comprising:  
receiving the fluid level signals from the fluid level sensor;  
and  
computing the fluid level in the tank, using a controller for  
the temperature control system, based on the fluid level  
signals received from the fluid level sensor.
18. The method of claim 17, further comprising:  
inhibiting nondeterministic fluid level signals from being  
received by the controller.

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